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Search for Technicolor Particle in $W^{\pm} + 2$ Jets with Secondary Vertex b-tagging

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Abstract

We present a search for Technicolor particles decaying into $b\bar{b}$ and produced in association with $W^{\pm}$ bosons in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. The search uses approximately 161.6 pb^{-1} for CEM and CMUP and 149.8 pb^{-1} for CMX of the dataset accumulated by the CDF collaboration at Fermilab Tevatron. Events with an electron or muon, missing E_T and two jets, one of them b-tagged, are selected. The number of tagged events and the invariant mass distributions of $W^{\pm} + 2$ jets and dijet are consistent with the Standard Model expectations. We set a 95% confidence level upper limit on the production cross section times branching ratio as a function of the Technicolor particle masses.

1 Introduction

For several decades, the Standard Model has been remarkably successful in explaining and predicting experimental data. However, the mechanism of electroweak symmetry breaking is still not known. The two most popular mechanisms to induce spontaneous symmetry breaking of a gauge theory, resulting in the gauge bosons and fermions acquiring masses, are the Higgs mechanism and the dynamics of a new interaction such as Technicolor. Both mechanisms predict the existence of a new particle X with unknown mass which could be produced at the Tevatron through $p\bar{p} \to W^{\pm}X$ with a production cross section of the order of 0.1 pb to 5 pb. Figure 1 shows the Feynman diagrams of $p\bar{p} \to W^{\pm}X \to \ell\nu b\bar{b}$. In this note we present a search for technirho ($\rho_T^{\pm}$) and technipion (π_T^0) using the SECVTX b-tagger. In terms of the Higgs boson search, we refer the reader to the separate CDF note [1].

The search signature considered here is $\rho_T^{\pm} \to W^{\pm}\pi_T^0$ with $W^{\pm} \to e\nu$ or $\mu\nu$, and $\pi_T^0 \to b\bar{b}$, giving final states with one high p_T lepton, large missing E_T ($\not\!\!E_T$) and two b jets. We focus our attention on the $W^{\pm} + 2$ jets signature since it contains most of the signal, while b-tagged $W^{\pm}+ \geq 3$ jets events are dominated by $t\bar{t}$ decays. Figure 2 shows the production cross section of $p\bar{p} \to \rho_T^{\pm} \to W^{\pm}\pi_T^0$ as a function of π_T^0 mass ($m(\pi_T^0)$) for different $m(\rho_T)$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

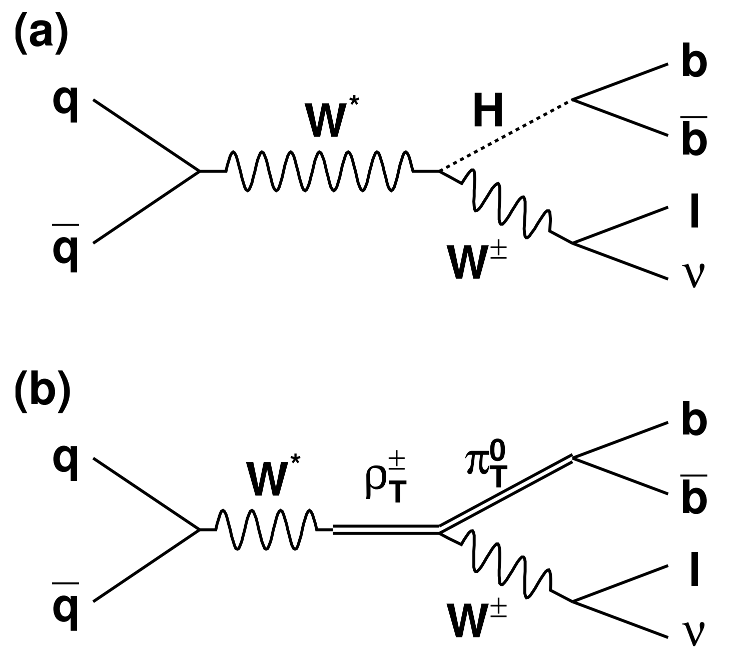


Figure 1: The Feynman diagrams of (a)$p\bar{p} \rightarrow W^* \rightarrow W^{\pm}H \rightarrow \ell\nu b\bar{b}$ and (b)$p\bar{p} \rightarrow W^* \rightarrow \rho_T^{\pm} \rightarrow W^{\pm}\pi_T^0 \rightarrow \ell\nu b\bar{b}$.

This note is organized as follows: Section 2 and 3 introduce the dataset and event selection. Section 4 presents the estimated number of events. Finally, Section 5 and 6 summarize the results and conclusion.

2 Data and MC samples

The data used in this analysis are from runs in the silicon good run list version 4 defined by the DQM group. In particular, good runs with numbers in the range 141544-167715 [1] represent an integrated luminosity of 161.6 ± 9.5 pb^{-1}. (The offline luminosity has been corrected by a factor of 1.019 [2] and assigned a 6% uncertainty [3].) The CMX muon dataset is limited to runs after 150145, a total of 149.8 ± 8.8 pb^{-1}. We use the official TopNtuples produced with offline version 4.11.1. Silicon tracks in these ntuples have been refit using the updated alignment and refitter available in 4.11.1.

We use the standard Monte Carlo samples provided by the top group for the background studies, see the details at the top web page for official MC samples. For the signal acceptance and systematic studies, we have generated many $\rho_T^{\pm} \rightarrow W^{\pm}\pi_T^0$ samples with PYTHIA and different $\rho_T^{\pm}$ and π_T^0 masses using the standard Monte Carlo procedures outlined in 4.9.1.

3 Event Selection

The event selection starts with the standard $W^{\pm}+$ jets sample of the top analysis [4]. The baseline cuts for a good lepton are summarized in Table 1, 2 and 3. We require events to pass the ELECTRON_CENTRAL_18 trigger for CEM electrons, the MUON_CMUP18 trigger for CMUP muons,

[1] We remove run 164844 (CLC error), 163463 and 163474 (wrong beamline) from the good runs.

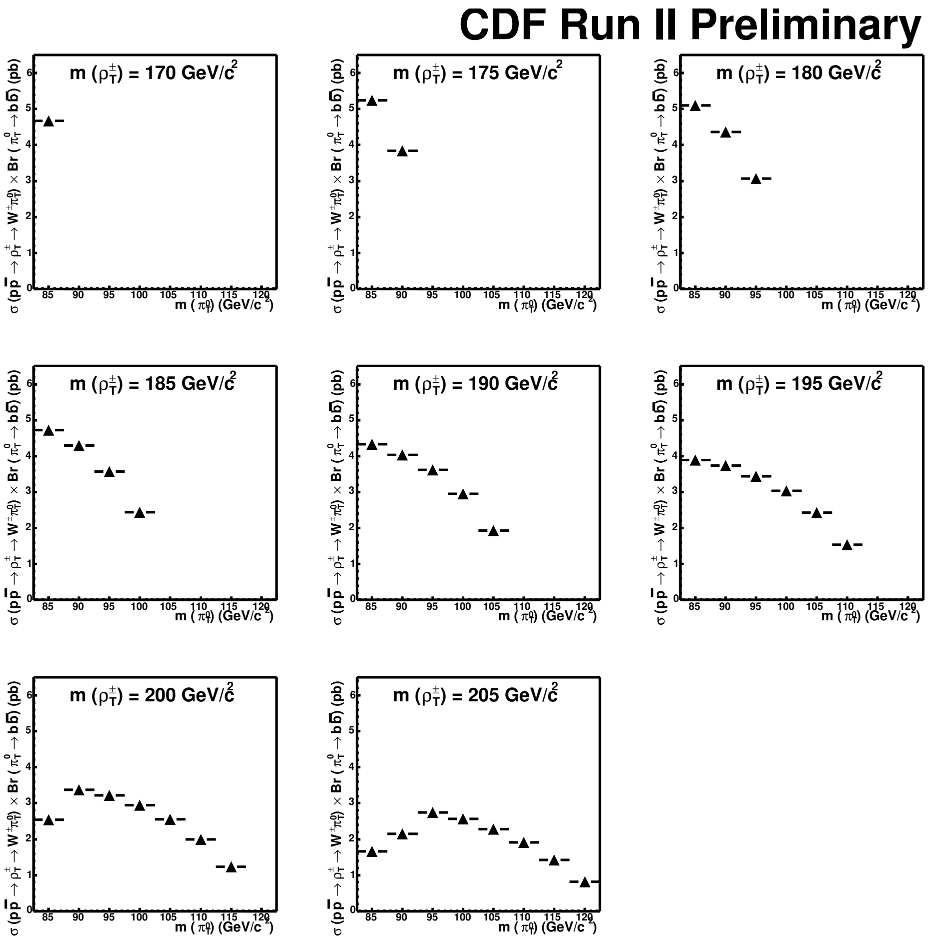


Figure 2: The $\rho_T^\pm \to W^\pm \pi_T^0$ production cross section as a function of the technipion mass ($m(\pi_T^0)$) for different $m(\rho_T)$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV.

and the MUON_CMX18 trigger for CMX muons. The expanded acceptance of the top dilepton cross section analysis necessitates an expanded veto for the lepton + jets analysis. We veto the events for which the sum of the tight central leptons and plug electrons are greater than 1. We use jet energies that have been corrected using level 4 jet energy corrections defined in Ref. [5]. $W^\pm$ boson events are selected by requiring that $\not{E}_T > 20$ GeV, where $\not{E}_T$ is corrected for the tight muon and all level 4 corrected jets in $|\eta| < 2.5$ and $E_T > 8$ GeV.

In addition to the $W^\pm$ boson event selections, events which are flagged as Z^0 boson and cosmic ray are removed. In order to further reduce the top contributions, we remove events with an additional high p_T isolated track ($p_T^{seed} > 20$ GeV/c) and charge opposite to the primary lepton. The track isolation is defined as $p_T^{seed}/(p_T^{seed} + \Sigma p_T) > 0.9$ where p_T^{seed} is the seed track p_T and Σp_T is the sum of track p_T (> 0.5 GeV) in a cone of radius 0.4 around the seed track. We also require that there are no any extra jets with $E_T^{raw} > 8$ GeV in the forward region ($2.0 <|\eta|< 3.0$) or two more extra jets with $E_T^{raw} > 8$ GeV and $E_T < 15$ GeV in the central region ($|\eta| < 2.0$), where E_T^{raw} is the uncorrected jet E_T.

To classify the remaining events according to jet multiplicity, we select the jets with $E_T > 15$ GeV and $|\eta| < 2.0$. The $W^\pm + 2$ jets bin is expected to contain most of the signal, while the other bins are used to check the background calculation. In order to enhance the signal in the $W^\pm + 2$ jets

Central Electron Variable	Value
Fiducial and CEM	$= 1$
E_T	≥ 20 GeV
p_T	≥ 10 GeV/c
E/p (if $p_T \leq 100$ GeV/c)	≤ 2.0
E_{HAD}/E_{EM}	$\leq 0.055 + 0.00045 \times E$
L_{shr}	≤ 0.2
$\mid \Delta z \mid$	≤ 3 cm
$Q \times \Delta x$	≥ -1.5 and ≤ 3.0 cm
χ^2_{strip}	≤ 10
$\mid \Delta z_0 \mid$	≤ 60 cm
$\mid z_0^{vtx} - z_0^{electron} \mid$	≤ 5 cm
Good COT Axial Segments	≥ 3
Good COT Stereo Segments	≥ 3
Isolation	≤ 0.1
Not a conversion	$\Lambda > 0.03$ or $\Delta r > 0.3$

Table 1: CEM electron selection criteria.

bin, we require that at least one of the jets be b-tagged by the SECVTX algorithm. Figure 3 shows an event display for the double tagged event in the $W^{\pm} + 2$ jets sample.

4 Event Estimation

The following backgrounds must be accounted for in the tagged $W^{\pm}$ + jets sample:

- Mistags or false tags due to vertex and track resolution,
- $W^{\pm} + b\bar{b}$, $W^{\pm} + c\bar{c}$ and $W^{\pm} + c$,
- non-$W^{\pm}$ (QCD),
- $t\bar{t}$, single top, W^+W^-, $W^{\pm}Z^0$, Z^0Z^0 and $Z^0 \rightarrow \tau^+\tau^-$.

We refer the reader to section 5 of Ref. [1], since we apply the same cut and use the same dataset as the $W^{\pm}H \rightarrow \ell\nu b\bar{b}$ analysis.

Figure 4 and Table 4 summarize the number of observed tagged events along with the estimated background events. The expectations are in reasonably good agreement with the $W^{\pm}+$ jets data.

5 Results

5.1 Acceptance

The acceptance for identifying $\rho_T^{\pm} \rightarrow W^{\pm}\pi_T^0 \rightarrow \ell\nu b\bar{b}$ events is calculated from a combination of data and PYTHIA Monte Carlo samples of $p\bar{p} \rightarrow \rho_T^{\pm} \rightarrow W^{\pm}\pi_T^0 \rightarrow W^{\pm}b\bar{b}$ events as a function of $m(\rho_T^{\pm})$ and $m(\pi_T^0)$ using the cuts described above. We apply the trigger efficiencies of 0.9656 ± 0.0006, 0.887 ± 0.007 and 0.954 ± 0.006 [6, 7] for CEM, CMUP and CMX, respectively. The same scale factors for lepton identification (ID) and muon reconstruction efficiencies are applied[4]

Plug Electron Variable	Value
E_T	$\geq$ 20 GeV
E_{HAD}/E_{EM}	≤ 0.05 (if $E_T \leq 100$ GeV)
	$\leq 0.05 + 0.026 \times \log(E_{EM}/100.0)$ (if $E_T > 100$ GeV)
Towers in χ^2 fit	≥ 1
PEM 3×3 χ^2	≤ 10.0
PES U cluster 5×9 ratio	> 0.65 (if $E_T < 100$ GeV)
PES V cluster 5×9 ratio	> 0.65 (if $E_T < 100$ GeV)
PES η	$> 1.2, < 2.5$
Number PES clusters	≥ 1
ΔR PEM-PES	$\leq$ 3 cm
Phoenix match	Yes
Track $\mid z_0 \mid$	$\leq$ 60 cm
Number PHX Si hits	≥ 3
Isolation	≤ 0.1

Table 2: PEM electron selection criteria.

Central Muon Variable	Value
Region	CMUP or CMX
p_T	$\geq$ 20 GeV/c
E_{EM}	$\leq \max(2, 2 + 0.0115 \times (p - 100))$
E_{HAD}	$\leq \max(6, 6 + 0.0280 \times (p - 100))$
$\mid \Delta x \mid_{CMU}$	$\leq$ 3.0 cm
$\mid \Delta x \mid_{CMP}$	$\leq$ 5.0 cm
$\mid \Delta x \mid_{CMX}$	$\leq$ 6.0 cm
$\mid z_0 \mid$	$\leq$ 60 cm
$\mid z_0^{vtx} - z_0^{muon} \mid$	$\leq$ 5 cm
$\mid d_0 \mid$ if no Si hits	$\leq$ 0.2 cm
$\mid d_0 \mid$ if Si hits	$\leq$ 0.02 cm
Good COT Axial Segments	≥ 3
Good COT Stereo Segments	≥ 3
Isolation	≤ 0.1
COT exit radius (CMX-only)	$\geq$ 140 cm

Table 3: CMUP and CMX muon selection criteria.

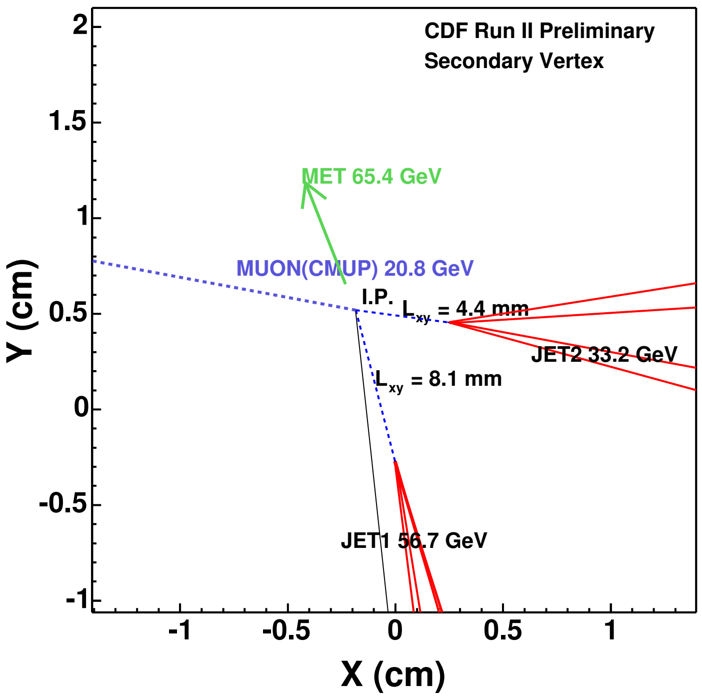


Figure 3: The event display for the double tagged event (run 166063, event 279746) in $W^\pm + 2$ jets sample.

in order to account for differences in the efficiencies between data and simulation. The scale factor for the SECVTX b-tagging efficiency is 0.82 ± 0.06 (stat.+sys.) [8, 9]. Although the scale factor for the c-tagging efficiency has not been measured, we have no reason to expect it to be very different from the scale factor for b-tagging. We take 0.82 ± 0.12 (stat.+sys.) for c-tagging, with an increased systematic error to account for extra uncertainty. The total acceptance is calculated as a production of the kinematic and geometric acceptance, the lepton ID efficiency, the trigger efficiency and the b-tagging efficiency. A 12% systematic uncertainty comes from uncertainties in the modeling of initial (4%) and final (7%) state radiations, the parton distribution function (2%), the jet energy scale (3%), the b-tag efficiency (6%), jet energy smearing [2] [10] (1%), the soft jet modeling (1%), the electron and muon trigger efficiencies ($0.06\%, 0.79\%, 0.63\%$ for CEM, CMUP and CMX, respectively), the electron and muon ID efficiencies (5%). The acceptance increases linearly from $0.9 \pm 0.2\%$ to $1.5 \pm 0.2\%$ as $m(\rho_T^\pm)$ and $m(\pi_T^0)$ increase, shown in Figure 5.

5.2 95% C.L. upper limit

We perform a direct search for a resonant mass peak in the reconstructed $W^\pm + 2$ jets and dijet invariant mass distributions with level 7 jet energy correction.

To reconstruct the $W^\pm + 2$ jets mass, we need to determine the p_z of neutrino from $W^\pm$ boson. We use $W^\pm$ mass constraint in the lepton-neutrino system. We take the smaller p_z from the two solutions. If there is no solution for p_z, we take the real part of the solution of the quadratic equation. Figure 6 shows the reconstructed neutrino momentum vs the generator neutrino momentum using $W^\pm H \rightarrow \ell\nu b\bar{b}$ sample ($m_H = 115$ GeV/c^2), which indicates a clear correlation between two

[2] The difference of jet energy resolution between data and MC.

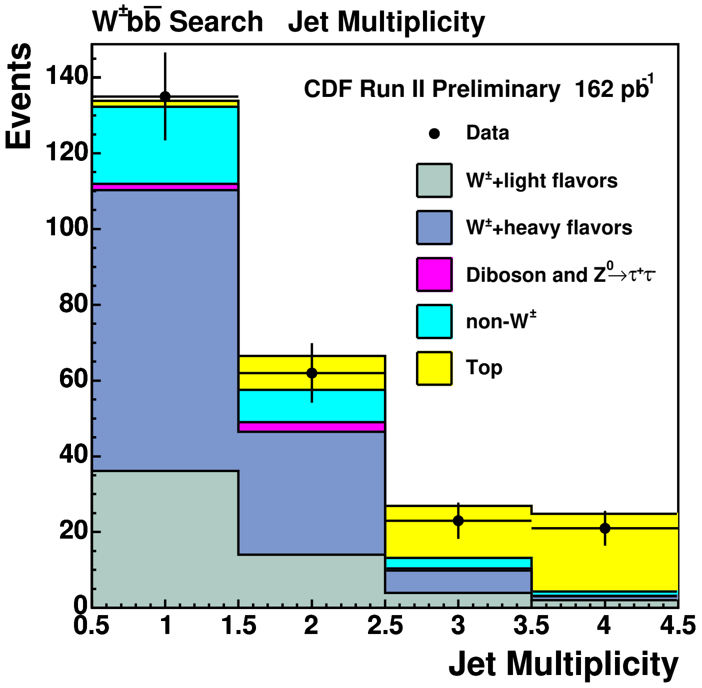


Figure 4: The number of observed positive tagged events and the background summary as a function of jet multiplicity. The integrated luminosities are 161.6 pb^{-1} for CEM and CMUP and 149.8 pb^{-1} for CMX.

momenta. Figure 7 shows $W^\pm + 2jets$ mass distribution for with and without no p_z solution events using signal sample. Since the no p_z solution events don't change the $W^\pm + 2$ jets mass distribution, we use these events to search for the Technicolor particles.

Figures 8 and 9 show the $W^\pm + 2$ jets and dijet mass distributions. Since there are no mass peaks observed from $\rho_T^\pm$ and π_T^0, we set an upper limit on the production cross section times branching ratio of $p\bar{p} \to \rho_T^\pm \to W^\pm \pi_T^0$ as a function of $m(\rho_T^\pm)$ and $m(\pi_T^0)$ by using the number of events in the $W^\pm + 2$ jets sample. We assume the $W^\pm + 2$ jets and dijet mass distributions in the data to consist of QCD (mistags, $W^\pm + b\bar{b}$, $W^\pm + c\bar{c}$, $W^\pm + c$ and diboson), TOP ($t\bar{t}$ and single top) and $\rho_T^\pm \to W^\pm \pi_T^0$ events. A 2-dimensional binned maximum likelihood technique is used to estimate the number of $\rho_T^\pm \to W^\pm \pi_T^0$ signal events by constraining the number of QCD and TOP events to the expectation within the statistical and systematic uncertainties. Figure 10 show the mass correlation between the $W^\pm +$ 2jets mass and the dijet mass for $\rho_T^\pm \to W^\pm \pi_T^0 \to \ell\nu b\bar{b}$, $W^\pm + 2$ jets, QCD and TOP. The advantage of the 2-dimensional likelihood is to treat the mass correlation properly. The expected number of events (μ) in each mass bin is

$$\mu = f_{QCD} \cdot N_{QCD} + f_{TOP} \cdot N_{TOP} + f_{\rho_T^\pm \to W^\pm \pi_T^0} \cdot (\varepsilon \cdot \mathcal{L} \cdot \sigma_{\rho_T^\pm \to W^\pm \pi_T^0}),$$

where f_{QCD}, f_{TOP} and $f_{\rho_T^\pm \to W^\pm \pi_T^0}$ are the expected fraction of events in a given mass bin predicted by Monte Carlo. N_{QCD}, N_{TOP}, ε, $\mathcal{L}$ and $\sigma_{\rho_T^\pm \to W^\pm \pi_T^0}$ are the expected number of QCD and TOP events, the detection efficiency, the luminosity and the unknown $\rho_T^\pm \to W^\pm \pi_T^0$ cross section respectively.

Background	$W^{\pm}+1$ jet	$W^{\pm}+2$ jets	$W^{\pm}+3$ jets	$W^{\pm}+\geq 4$ jets
Events before tagging	13408	2072	314	82
Mistags	36.15 ± 7.06	14.06 ± 2.58	3.98 ± 0.86	2.05 ± 0.45
$W^{\pm}+b\bar{b}$	32.19 ± 10.17	19.10 ± 5.87	3.67 ± 1.08	0.66 ± 0.20
$W^{\pm}+c\bar{c}$	11.92 ± 3.53	6.83 ± 2.18	1.20 ± 0.41	0.23 ± 0.09
$W^{\pm}+c$	29.96 ± 8.04	6.54 ± 1.81	1.03 ± 0.31	0.12 ± 0.05
Diboson/$Z^0 \to \tau^+\tau^-$	1.73 ± 0.60	2.50 ± 0.63	0.50 ± 0.11	0.10 ± 0.04
non-$W^{\pm}$	20.33 ± 2.00	8.53 ± 1.18	2.80 ± 0.47	1.14 ± 0.24
$t\bar{t}$	0.43 ± 0.10	5.15 ± 0.96	12.84 ± 2.36	20.32 ± 3.72
single top	1.16 ± 0.15	3.81 ± 0.48	0.90 ± 0.12	0.17 ± 0.03
Total Background	133.86 ± 17.52	66.52 ± 8.97	26.94 ± 3.16	24.78 ± 3.83
Observed positive tags	135	62	23	21

Table 4: The number of observed positive tagged events and the background summary for an integrated luminosity of 161.6 pb^{-1} for CEM and CMUP and 149.8 pb^{-1} for CMX.

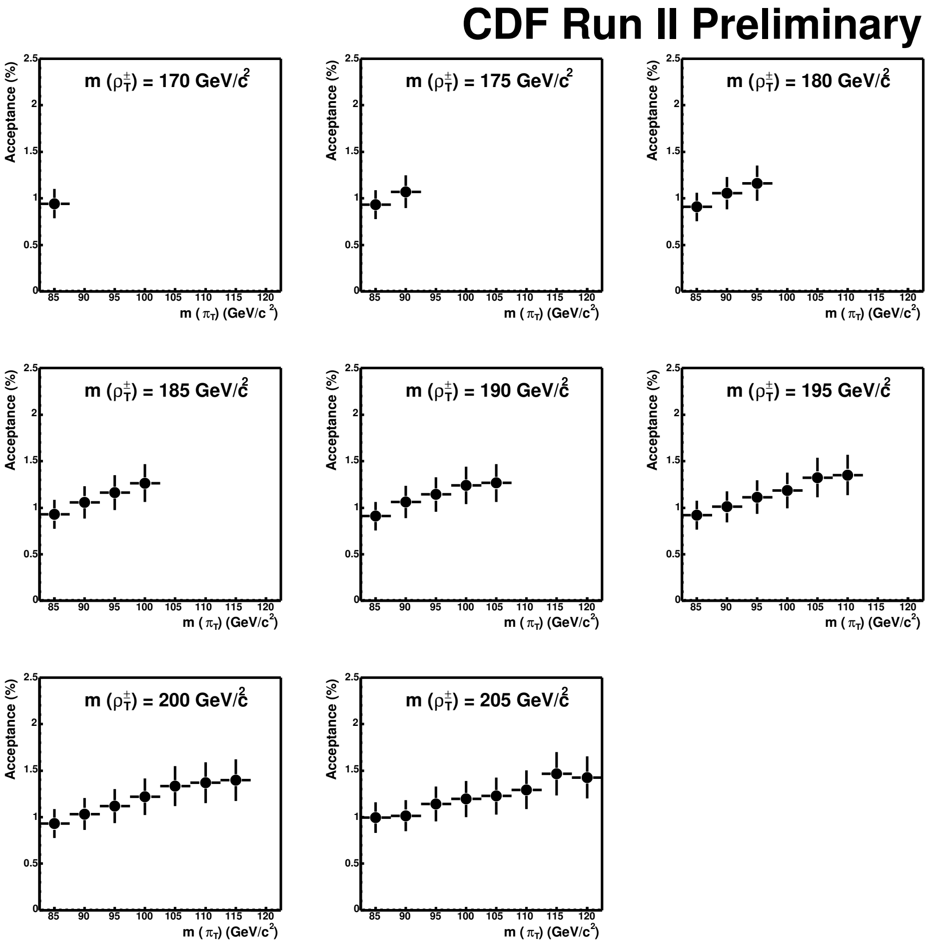


Figure 5: The total $\rho_T^{\pm} \to W^{\pm}\pi_T^0 \to \ell\nu b\bar{b}$ acceptance as a function of the technipion mass ($m(\pi_T^0)$) for the different technirho mass ($m(\rho_T^{\pm})$).

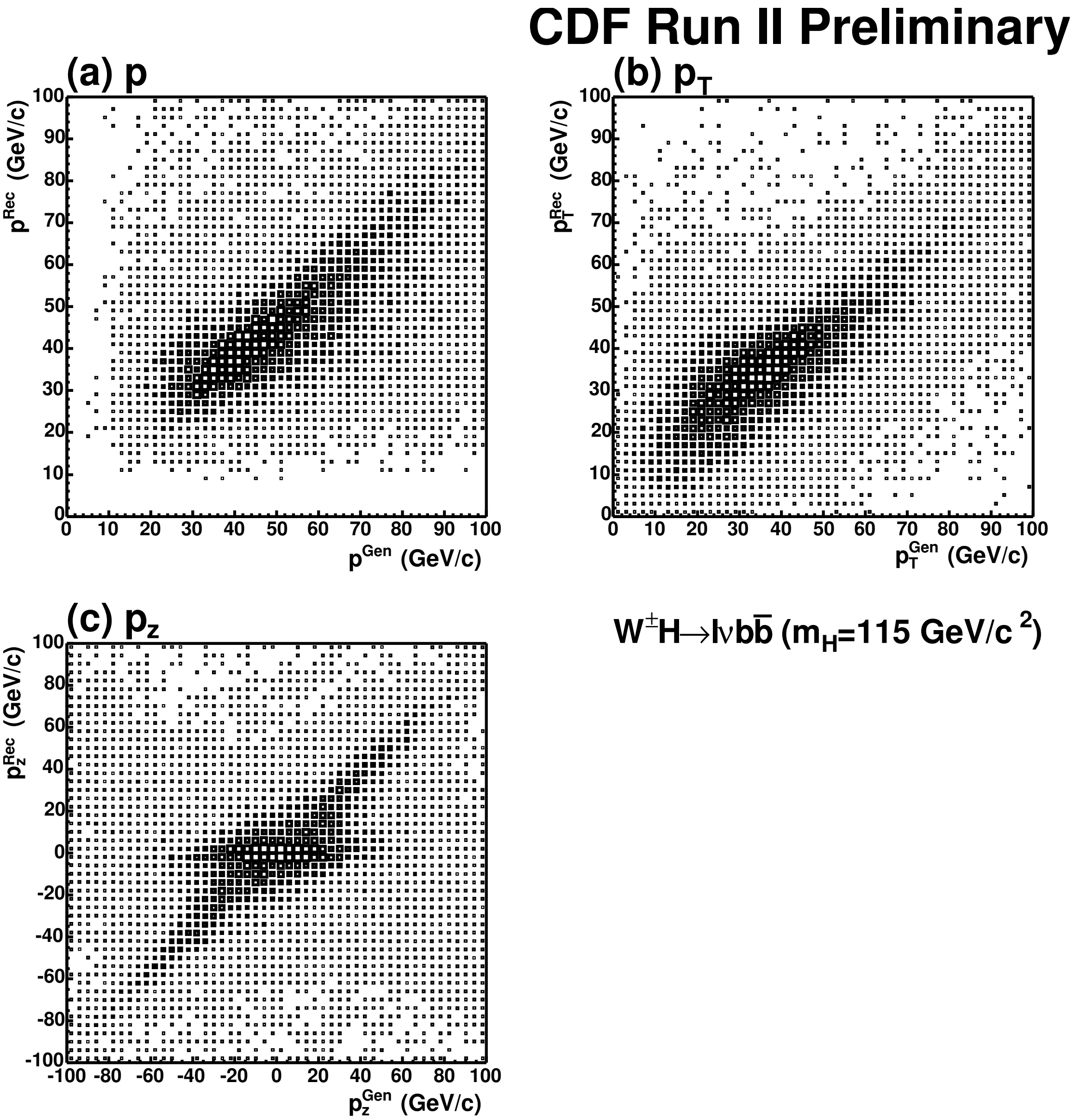


Figure 6: Reconstructed neutrino momentum vs. Generator neutrino momentum. (a)p, (b)p_T, (c)p_z.

The corresponding likelihood is

$$L = \prod_{i=bin} \frac{\mu_i^{N_i} \cdot e^{-\mu_i}}{N_i!},$$

where N_i is the observed events from the $W^{\pm}+2$ jets sample. Figure 12 shows the 95% C.L. upper limit and pseudo experiment results as a function of $m(\pi_T^0)$ for different $m(\rho_T)$. The sensitivity of the present search is still limited by statistics, but is getting close to some of theoretical cross section, As shown in Figure **??** for the ratio of measured cross section limit and PYTHIA prediction in the $\rho_T^{\pm}$ and π_T^0 mass plane.

6 Conclusion

We performed a search for new particles decaying into $b\bar{b}$ and produced in association with a $W^{\pm}$ boson at the Run 2 dataset. The $W^{\pm}+2$ jets and dijet mass spectra show no significant excess of events in the b-tagged $W^{\pm}+2$ jet events. We set a 95% C.L. upper limit on the production cross section times branching ratios as a function of the technirho and technipion masses. From Figure 12, we see that the sensitivity of the present search is limited by statistics, and is getting close to the theoretical cross section. We should be able to either discover new Technicolor particles or exclude them in the near future.

7 Acknowledgments

We would like to thank many people for their insights and useful discussions on this subject. Special thanks to S. Mrenna and K. Lane for many useful discussions.

A Selection Efficiency

In this section we describe some details of the selection efficiency of the signal in $W^{\pm}+2$ bin. For the backgrounds, we refer the reader to the separate CDF note [1].

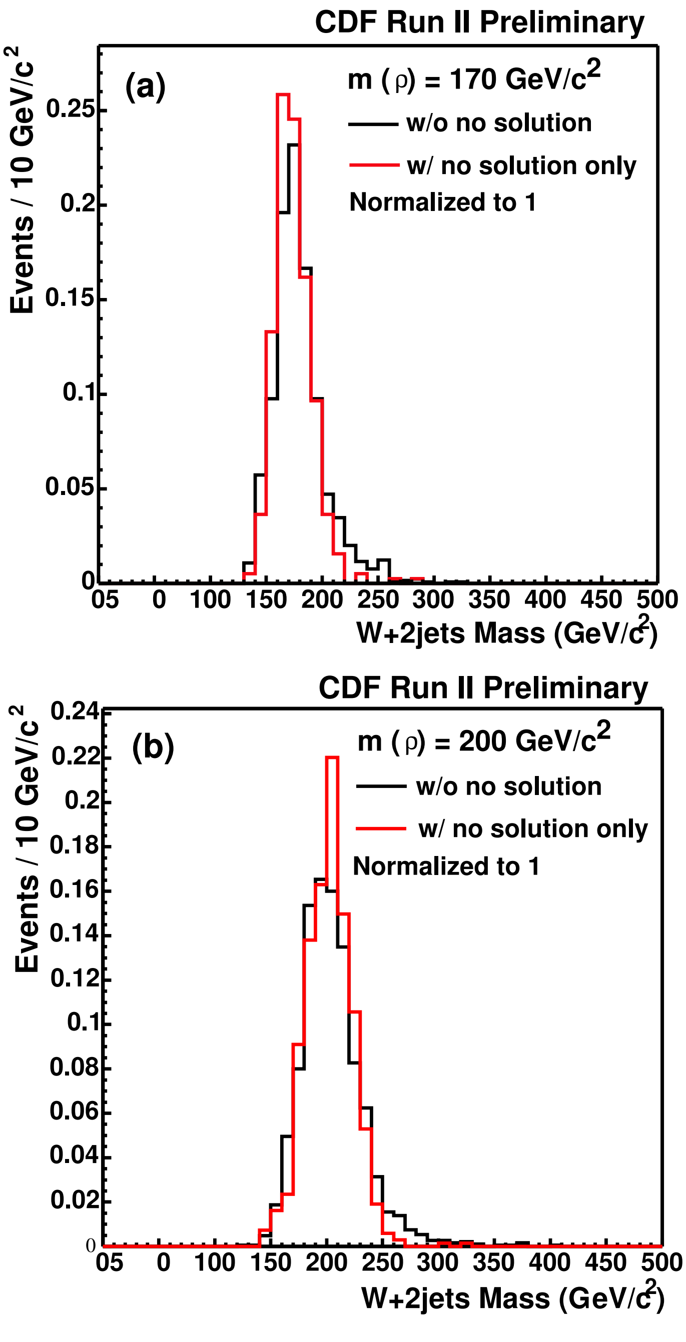


Figure 7: $W^{\pm} + 2$ jets mass distribution for with and without no p_z solution events using signal sample. (a)$m(\rho_T^{\pm}) = 175$ GeV$/c^2$, (b)$m(\rho_T^{\pm}) = 175$ GeV$/c^2$.

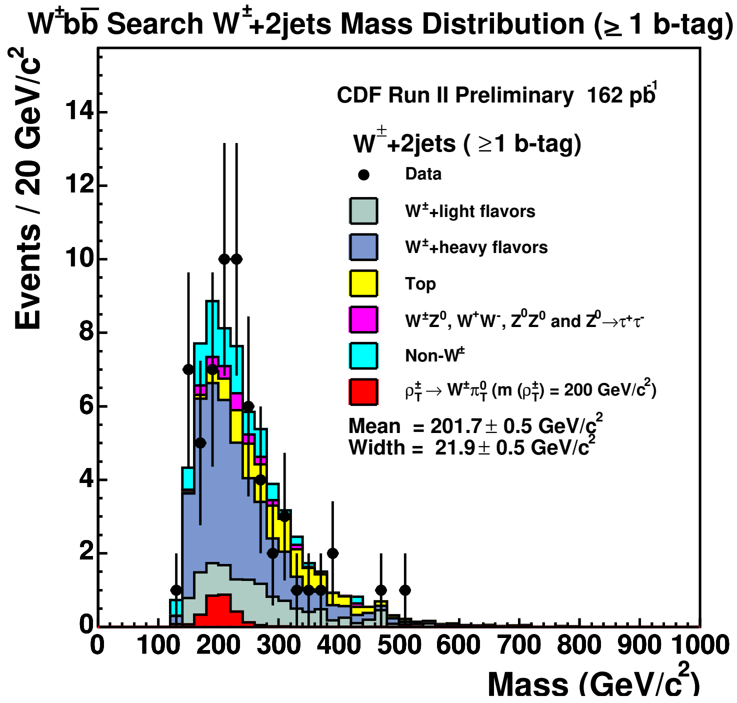


Figure 8: The $W^{\pm} + 2$ jets mass distribution in the data along with the background expectations.

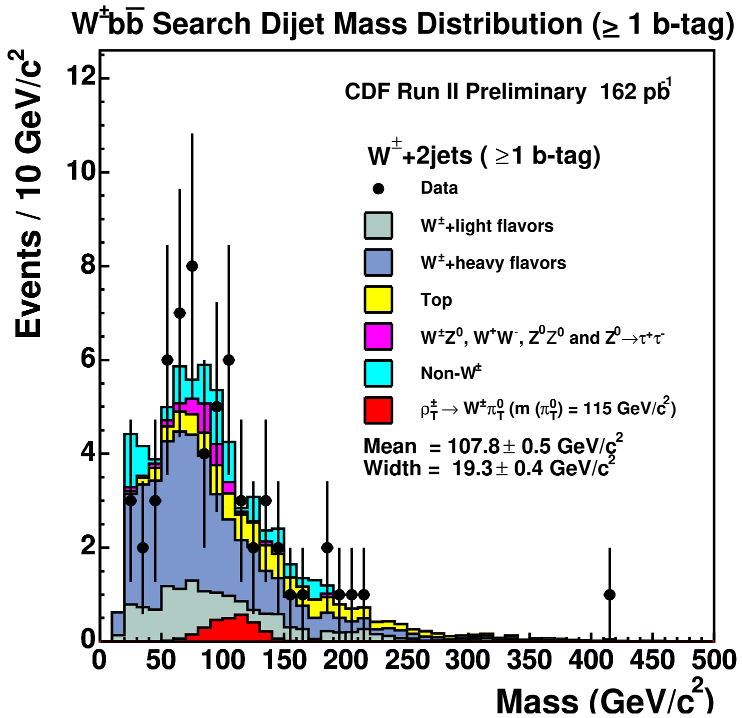


Figure 9: The dijet mass distribution in the data along with the background expectations.

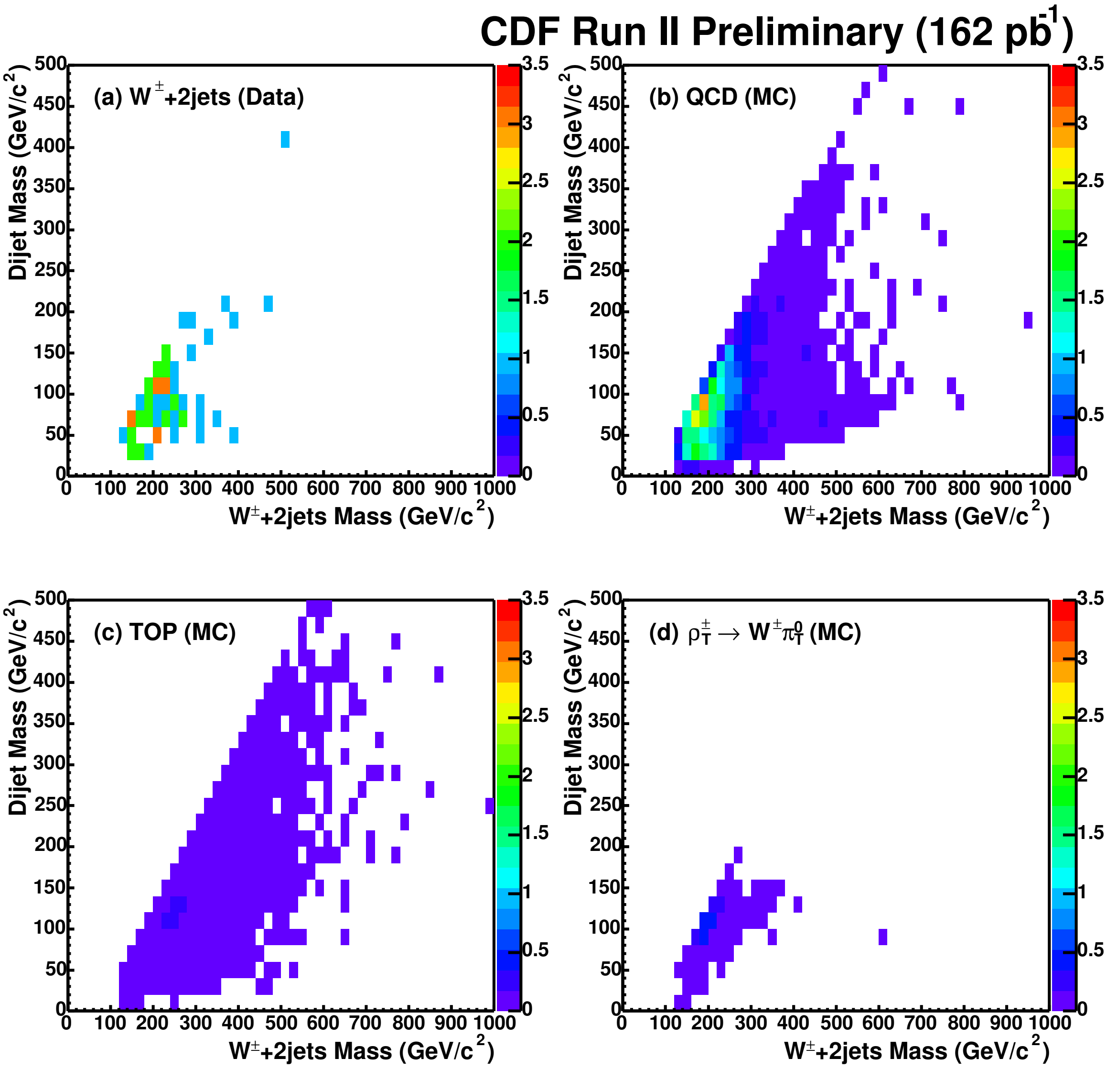


Figure 10: The dijet mass vs. $W^{\pm}$ + 2 jets mass distribution. (a)$W^{\pm}$ + 2 jets (Data), (b)QCD background (MC), (c)TOP background (MC), (d)$\rho_T^{\pm} \to W^{\pm}\pi_T^0$ (MC).

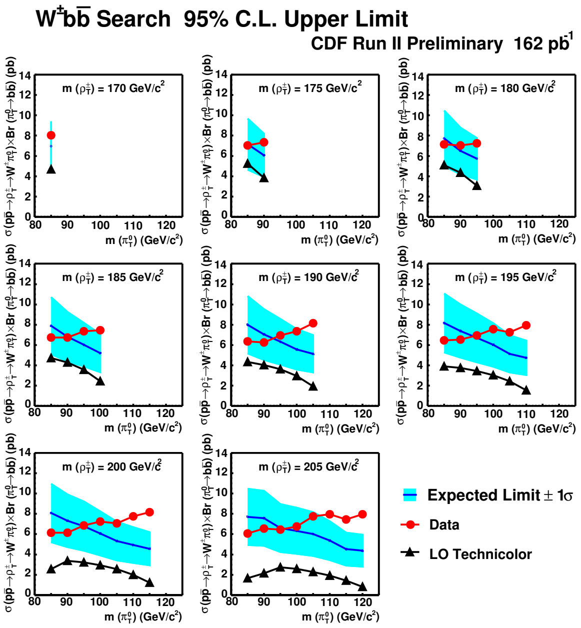


Figure 11: The 95% C.L. upper limit (red circle) on the $\rho_T^{\pm} \to W^{\pm}\pi_T^0$ cross section as a function of the technirho mass ($m(\pi_T^0)$) for the different technirho mass ($m(\rho_T^{\pm})$). Also shown is the theoretical cross section (black triangle) for the production of $\rho_T^{\pm} \to W^{\pm}\pi_T^0$, and the pseudo experiment results (blue square).

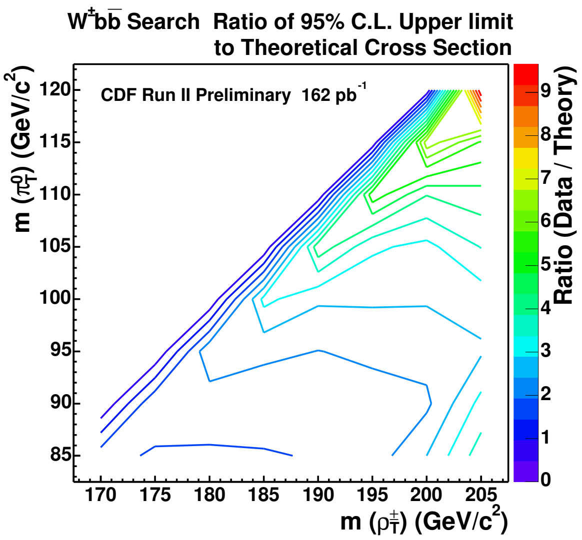
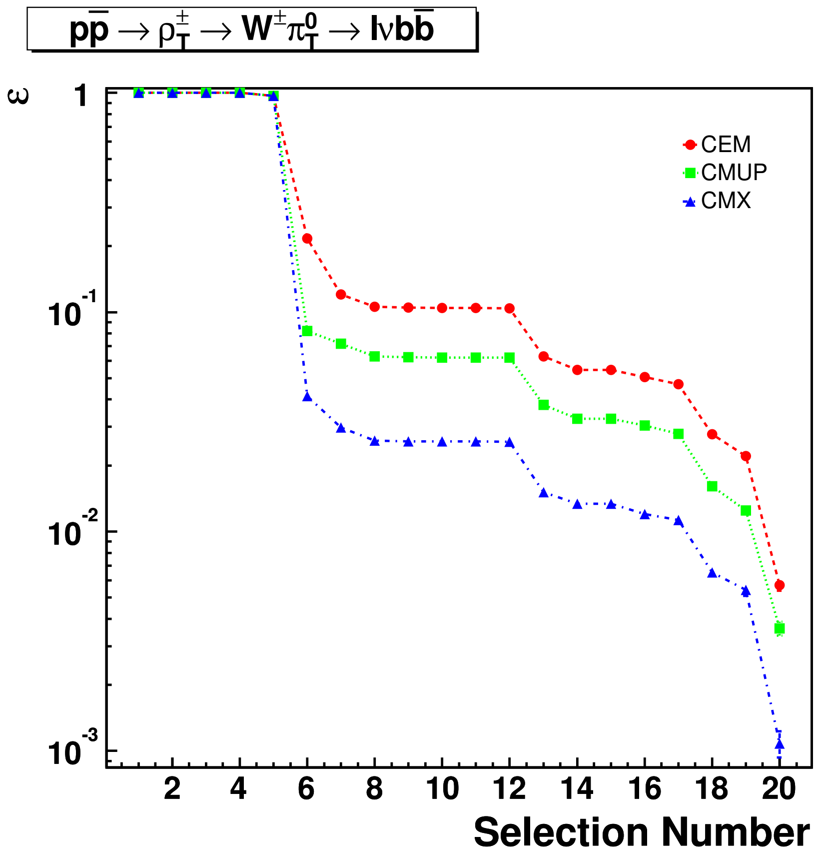


Figure 12: The ratio of measured 95% C.L. upper limit and PYTHIA predictions on the $p\bar{p} \to \rho_T^{\pm} \to W^{\pm}\pi_T^0 \to W^{\pm}b\bar{b}$ cross section is color coded in the $\rho_T^{\pm}$ and π_T^0 mass plane.

A.1 $p\bar{p} \to \rho_T^{\pm} \to W^{\pm}\pi_T^0 \to \ell\nu b\bar{b}$ ($m(\rho_T^{\pm}) = 200$ GeV, $m(\pi_T^0) = 115$ GeV/c^2)

Selection	CEM	CMUP	CMX
1. Initial	50000	50000	50000
2. Good si. align.	50000	50000	50000
3. Good run	50000	50000	50000
4. Trigger	50000	50000	50000
5. Obsp z vertex	48442	48442	48442
6. Lepton geom. ID	10820	4109	2068
7. Lepton ID	6023	3598	1491
8. Lepton Isol.	5294	3138	1298
9. !Dilepton	5251	3112	1289
10. !Z^0	5231	3110	1288
11. !Conv. or Cosmic	5218	3110	1288
12. !Isol. tracks	5215	3110	1284
13. # of jets = 2	3141	1888	757
14. Missing $E_T > 20$ GeV	2727	1633	669
15. $E_T^{jet1} > 15$ GeV	2727	1633	669
16. !# of extra jets	2535	1519	601
17. At least one tagg. jets	2345	1396	565
18. At least one tag	1388	805	325
19. Single tag	1103	624	271
20. Double tag	285	181	54



References

[1] Y. Ishizawa and W. Yao, Search for New Particles $X \to b\bar{b}$ Produced in Association with $W^{\pm}$ Bosons at $\sqrt{s} = 1.96$ TeV, CDF Note 6903.

[2] S. Klimenko, J. Konigsberg and T. Liss, Averaging of the inelastic cross-section measured by the CDF and the E811 experiments, CDF Note 6314.

[3] D. Acosta *et al.*, A First Look at the CLC Luminosity Measurements, CDF Note 6052.

[4] K. Bloom, K. Ebina, E. Thomson, K. Yorita and the Lepton + Jets Working Group, $t\bar{t}$ Event Selection and Detection Efficiency for Winter 2004 Lepton + Jets Analysis, CDF Note 6844.

[5] J.-F. Arguin *et al.*, Jet Corrections for Summer 2003 Analysis (Offline Version 4.10.4), CDF Note 6565.

[6] Mircea Coca and Eva Halkiadakis, Central Electron Identification Efficiencies for the 200 pb^{-1} Run 2 Dataset, CDF Note 6580.

[7] Victoria Martin and Lucio Cerrito, Muon Cuts and Efficiencies for 4.11 Analysis, CDF Note 6825.

[8] D. Amidei, H. Bachacou, S. Miller, J. Nielsen, H. Ray and W. Yao, Updated Measurement of the $t\bar{t}$ Production Cross Section in the SECVTX Tagged Sample, CDF Note 6585.
H. Bachacou, J. Nielsen, W. Yao, Optimized Measurement of the $t\bar{t}$ Production Cross Section with SECVTX, CDF Note 6902.

[9] Henri Bachacou, Weiming Yao, Thomas Write, Efficiency of SecVtx B-Tag Used for 2004 Winter Conferences, CDF Note 6904.

[10] Private communication with Beate Heinemann.